

# *Chemical Constraints on the Formation and Evolution of Habitable Worlds*

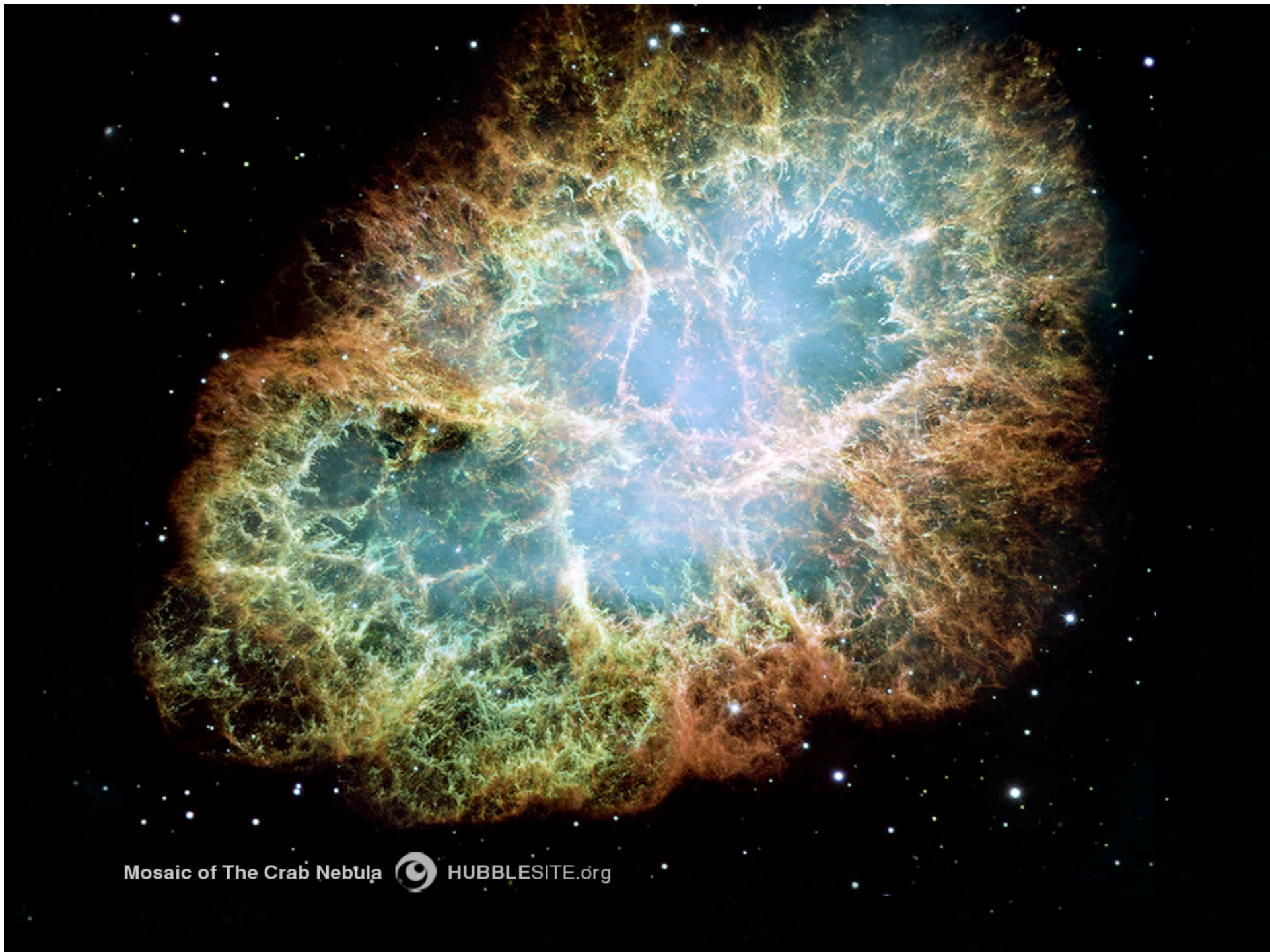



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# Scientific Goals:

- Summarize the carbon budget in the ISM.
- Follow the carbon through the formation of stars and evolution of planetary systems.
- Investigate the delivery of volatiles to terrestrial planets.

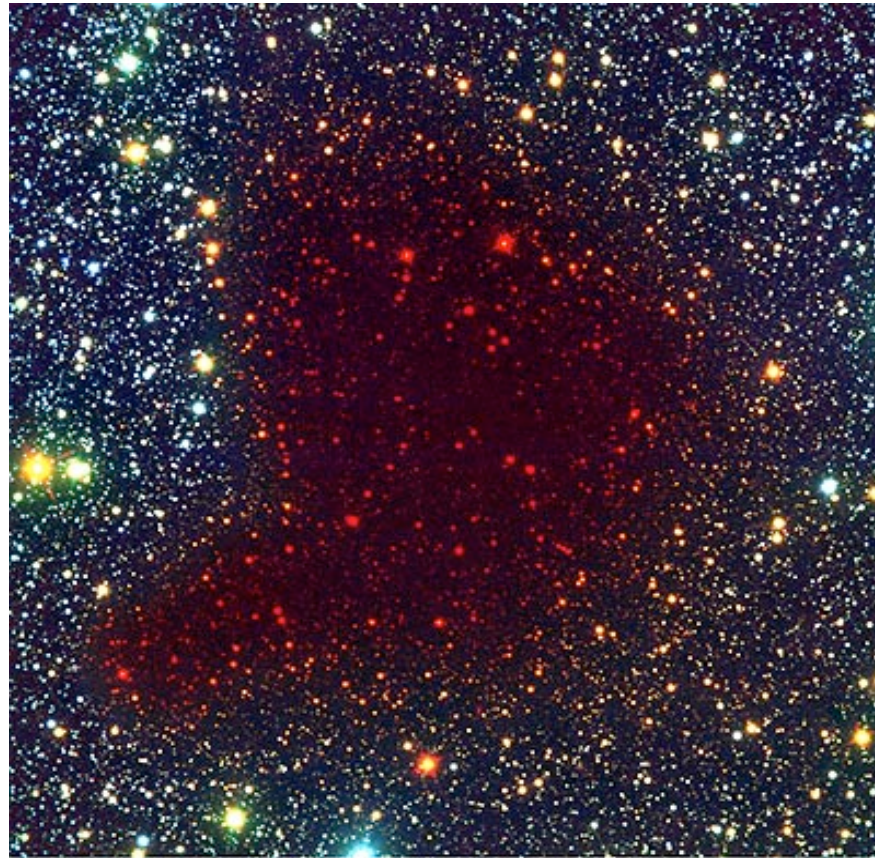
*Explain the carbon deficit in the inner solar system in the context of a theory of terrestrial planet formation that makes predictions concerning the frequency and nature of habitable worlds around stars in the Milky Way.*



Mosaic of The Crab Nebula  [HUBBLESITE.org](http://HUBBLESITE.org)



# Tearing Away the Cosmic Veil: Infrared Imaging and Spectroscopy

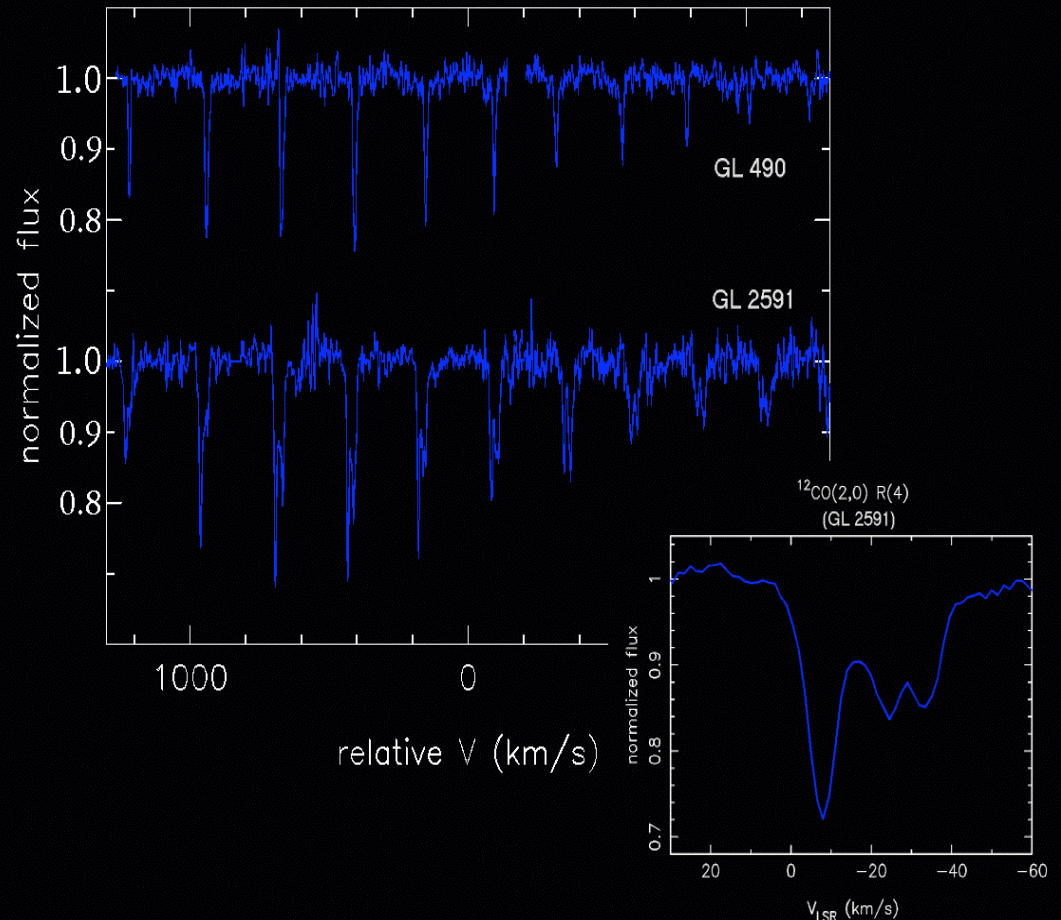
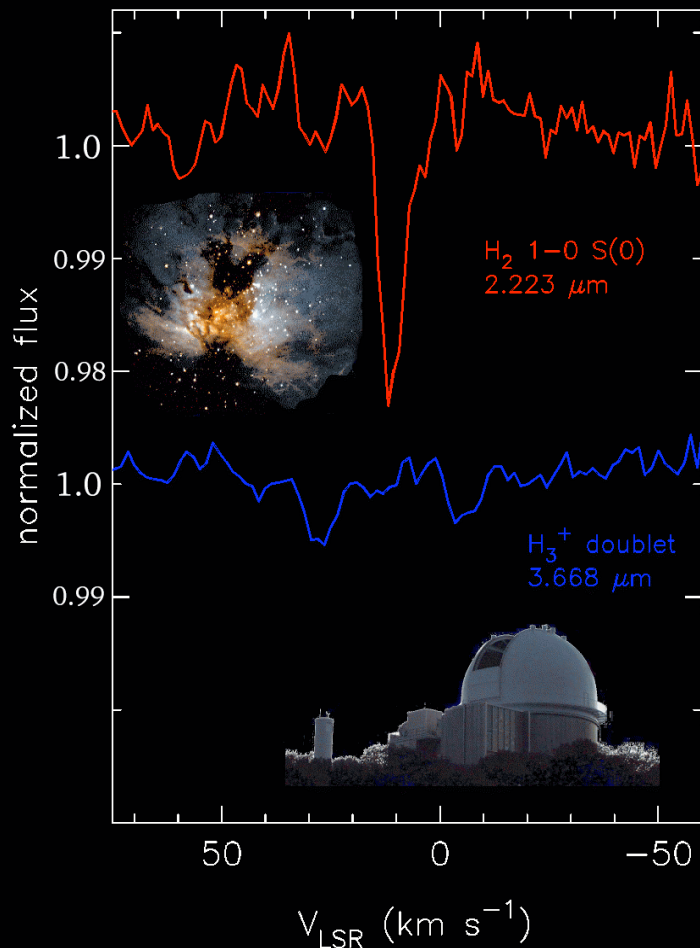


Seeing Through the Pre-Collapse Black Cloud B68  
(VLT ANTU + FORS 1 - NTT + SOFI)

# Measuring Gas Phase ISM Abundances:

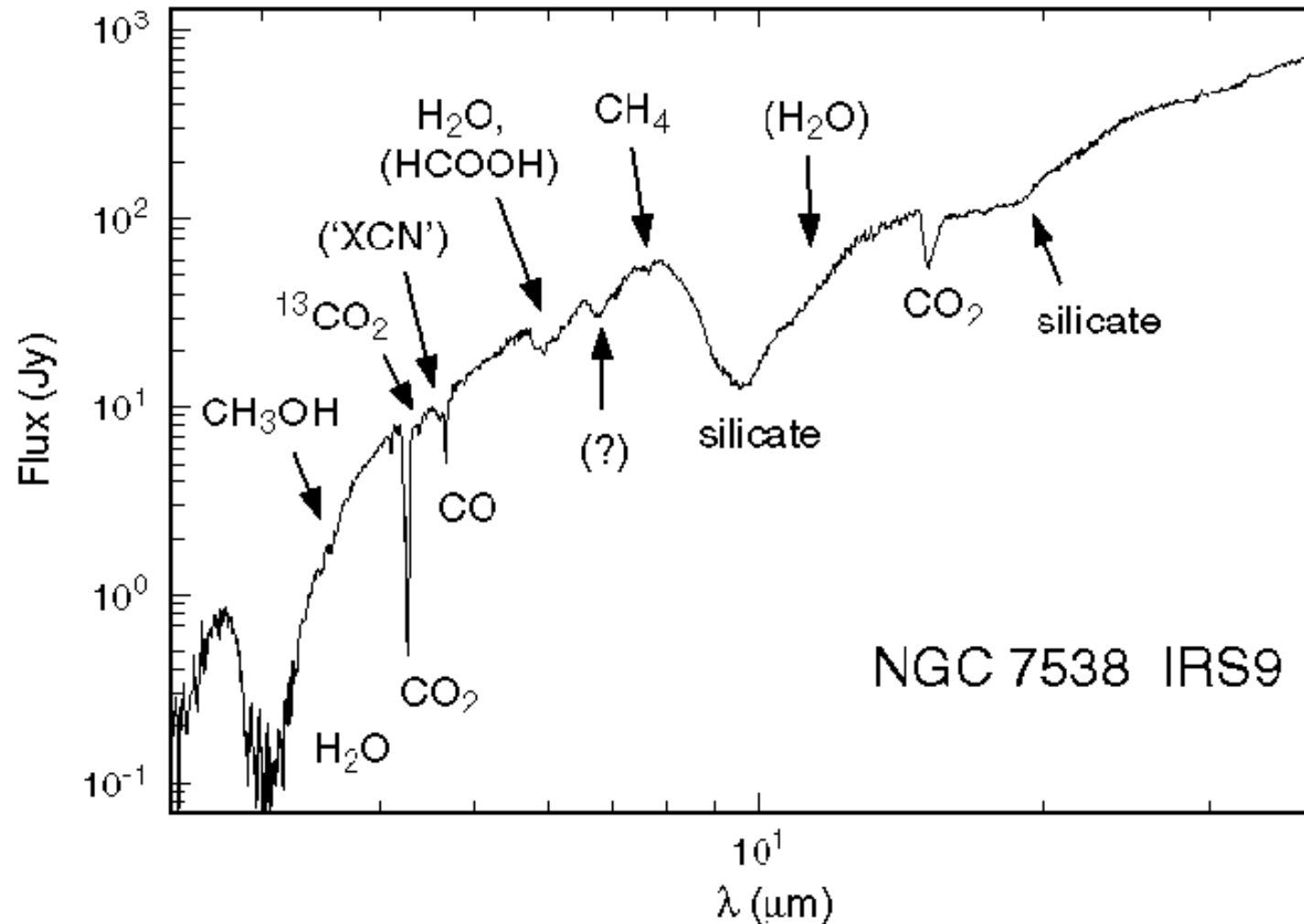
$\text{H}_2$  and  $\text{H}_3^+$  absorption toward NGC 2024 IRS 2

$^{12}\text{CO}(2,0)$  R(0)–R(10) towards AFGL 490 and AFGL 2591



First detection of  $\text{H}_3^+$  and  $\text{H}_2$  in same source (Phoenix at KPNO)  
Courtesy Craig Kulesa (U. Arizona)

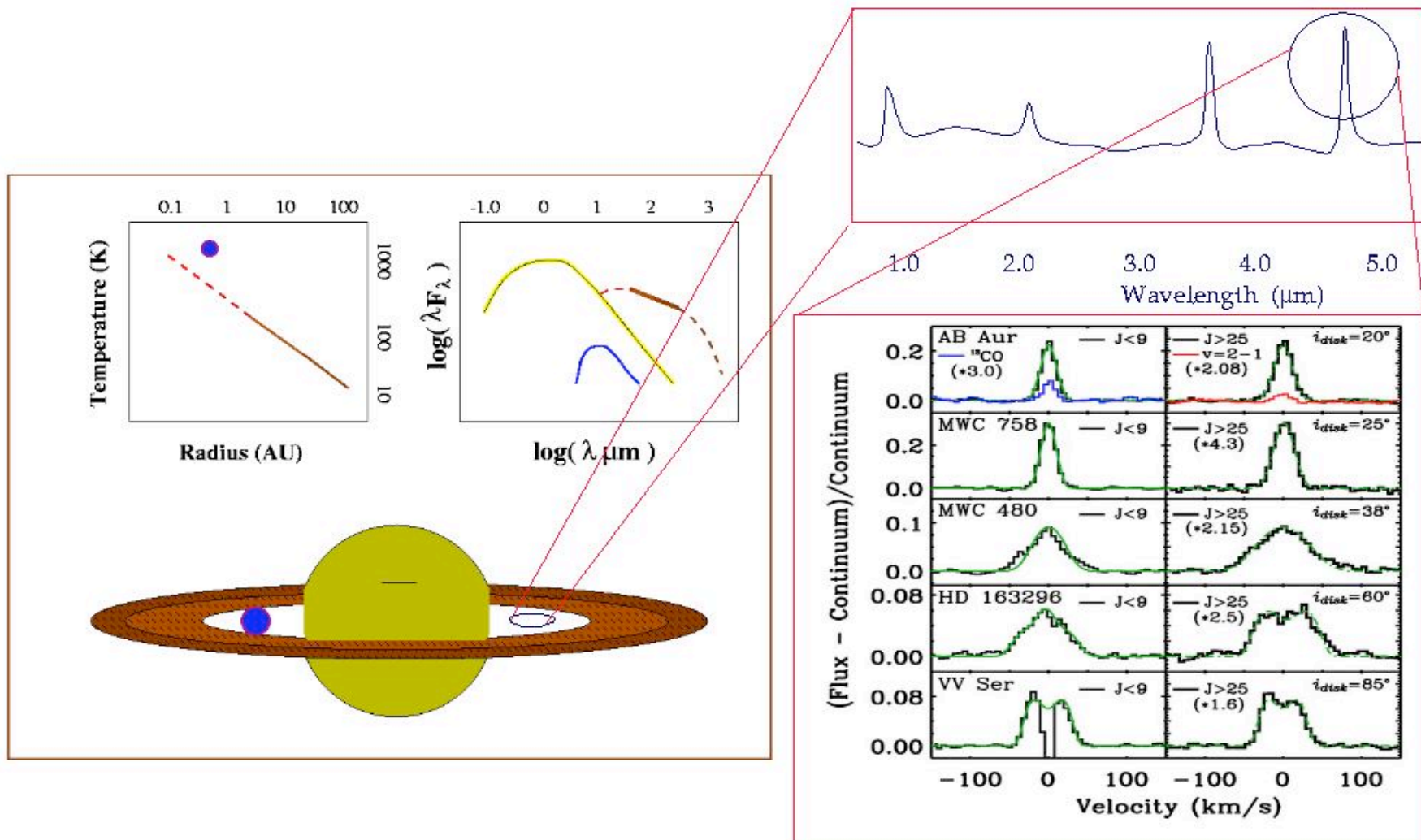
## 2.4 – 45 $\mu\text{m}$ spectrum of interstellar ices



*Follow the carbon...*



# Gas content as a function of radius and age.



Velocity resolved CO emission at 4.7 microns from Blake and Boogert (2004)



# *Terrestrial planets have been discovered!*

***Earth-mass planets discovered around  
pulsars***

***Wolszczan, A. (1994)***

***Debris disks also found around evolved  
stars.***

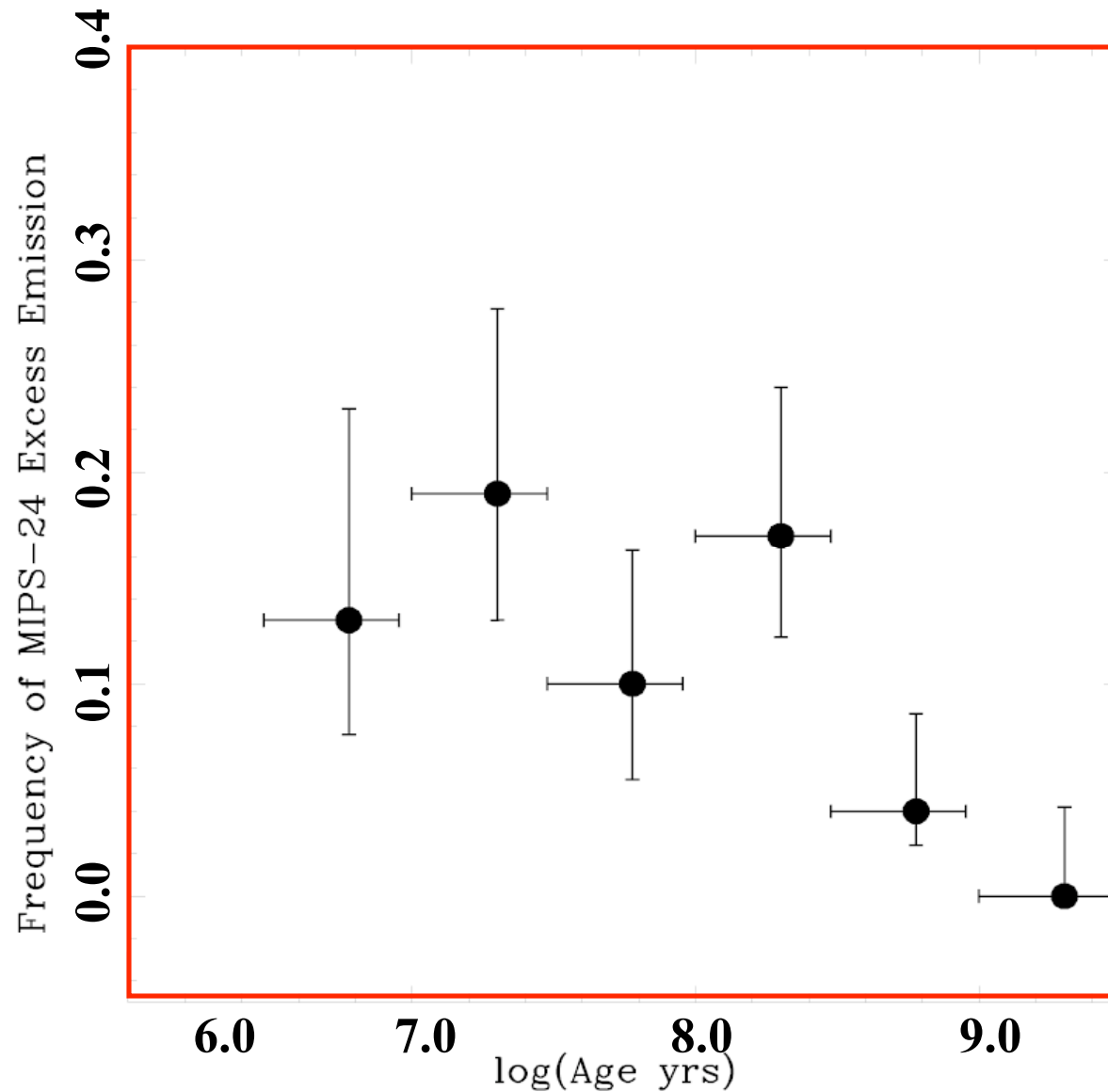
***Spitzer observations of warm debris around  
normal stars suggests terrestrial planets may  
be common***

***Meyer et al. (2008)***

***Su et al. (2006)***

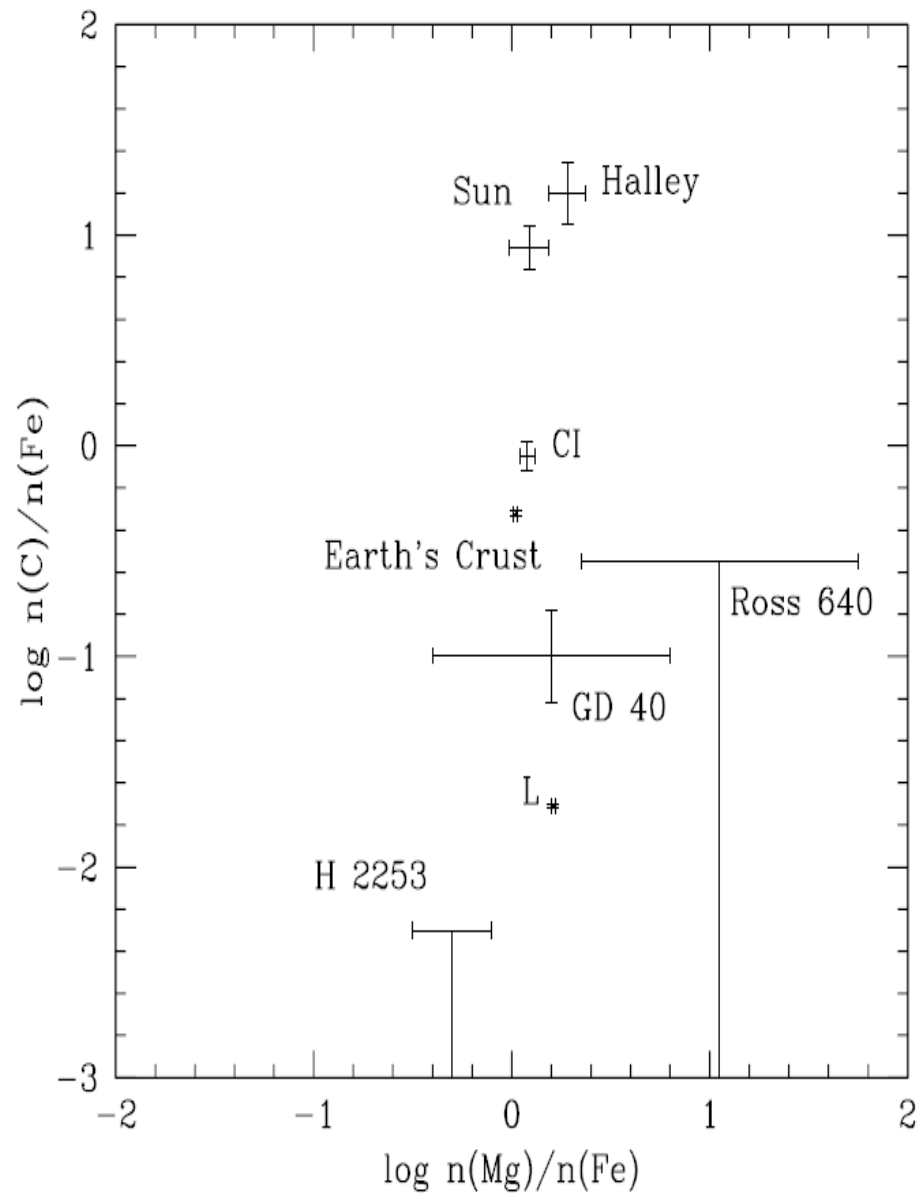
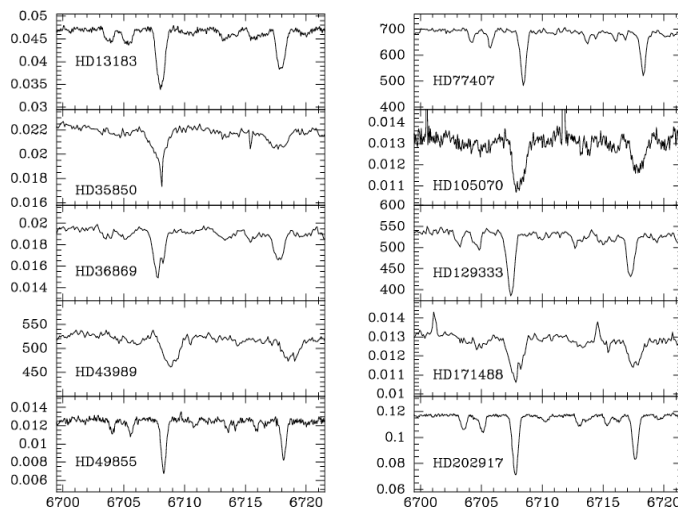


# Spitzer Provides Evidence of Planet Formation: Could Terrestrial Planets Outnumber Gas Giants?



Meyer et al. (2008); Kenyon & Bromley (2004; 2006)

# From Stellar Spectra to Planetesimal Composition:



**M. Jura (2006)**



# Key Investigations:

- Millimeter wave observations of the ISM and molecular clouds.
- Laboratory studies of meteorites and sample returns.
- Infrared spectroscopy of young stellar objects with ground- and space-based telescopes.
- Theoretical models of evolving disk chemistry.
- Observational study of the evolution of young stars: variability, x-ray / UV activity, and abundances.

# Strategic Impact on NASA:

- Key to Vision for Space Exploration.
  - » Inform searches for Earth-like planets and habitable environments of other stars.
  - » Understanding history of solar system.
- Guide planning / use of Spitzer, SOFIA, Herschel, Kepler, WISE, JWST, and other NASA-supported astronomical facilities.
- Guide exploitation / development of Stardust, Deep Impact, OSIRIS, and lunar exploration.
- Drive development / selection of TOPS, Astrobiology Explorer, TPF architectures.



# Participating Institutions:

- The University of Arizona / LAPLACE.
  - » Meyer, Lauretts, & Ziurys.
- University of California-Los Angeles:
  - » Young, Jura, others.
- Goddard:
  - » Mandell, Mumma, Charnely, others.
- CIW:
  - » Boss, Nitler, Ciesla, others.
- NASA-Ames: Davis.
- University of Hawaii: Meech.
- External Participant: E. Bergin (U. Michigan)